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IOP Conf. Series: Materials Science and Engineering **872** (2020) 012041 doi:10.1088/1757-899X/872/1/012041

Study of technologies implemented in the operation of SF6 switches

Sergio Díaz[1], José Nuñez[1], Kelly Berdugo[1], Kevin Gomez[1]

[1]Universidad de la Costa, Barranquilla, Atlántico Colombia.

[1]Email: sdiaz6@cuc.edu.co

Abstract. This research aims to evaluate the trends in the publication of papers on issues related to power circuit breakers, aimed at the technologies implemented, as well as those countries with higher level of publications, making a comparison between authors, research institutes, and a description of the last 10 years with more publications. All the information found in this report is compiled in bibliographic databases such as books of substation designs and research papers with a focus on electrical protection equipment and emphasis on high voltage switching devices. A technology research is conducted over the last ten years to analyze the state of the art of high voltage operating elements with respect to new technologies.

Keywords: Dielectric isolation, High-voltage switchgear, Switching mechanisms, Sulfur hexafluoride.

1. Introduction

Electrical substations in a power system perform the switching and transformation activities in order to operate an electrical system. Their performance is evaluated under scenarios of flexibility, reliability and security, complying with the minimum operating requirements to provide the scenarios that guarantee the stable functioning of the associated electrical networks in response to contingencies, maneuvers and operational changes in work [1].

Power circuit breakers are switching devices that open and close electrical loops in order to establish the continuity of the electrical circuit to which they are connected [2], thus collaborating with the stability required in the operation of the power system [3], where the circuit connection and disconnection actions must be performed both in normal operation and in the event of a fault [4]. It should be noted that when in no-load operation, the switch is known as a disconnector, and when in the open position or closed position under load, or when short-circuit current is flowing due to a fault, the switch is known as a circuit breaker or power circuit breaker [5].

The characteristics and functions of power circuit breakers in high-voltage substations are not only important in this process, but also in the entire chain of electricity generation and distribution in which there must be a high level of reliability in the interconnection with the network [6]. However, not all breakers are the same, and in order to make the appropriate selection it must be taken into account that there are different types determined by characteristics such as: voltage levels, installation site and

external design and mechanism. Another important characteristic is the way in which the current is interrupted, since circuit-breakers are built according to certain international technical standards and must comply with all the quality standards and certifications specified by the IEC 62271-100 [7] and ANSI C37.12 [8] norms.

Generally only two types of oil level switches are used, which are: live tank, with a low oil volume which is not connected to the ground, and is permanently exposed to high voltage; and the dead tank switch with a high oil level where its potential is connected to the potential surface of the ground, i.e. the safety grounding [9]. Both types of switchgear have different insulators depending on the location of the substation, whether it is an AIS (Air Insulated Substation) or GIS (Gas Insulated Substation) and the needs of the system [10].

The present study aims to characterize a research focused on SF6 type circuit breakers, from a bibliometric perspective. This study seeks to analyze the evolution of scientific production in recent years, in order to select the types of power circuit breakers that can be used according to their operating mechanism and that have no impact on the environment.

2. Methodology

As part of the research, a documentary analysis was carried out based on the theory of circuit breakers for substations, starting with the most classic definition of a circuit breaker, followed by the theory of its operation. This was done in order to understand the main concepts, the analysis of the characteristics based on their construction and configuration, allowing the review of the state of the art for power circuit breakers applied in SF6 technology, and how it manages to establish their operating parameters and internal composition. In the same way, the insulating and dielectric properties of SF6 technology breakers are analyzed. It is necessary to mention that there are many advances for this gas, which seek to adopt an ecological approach due to the environmental impact that their implementation is causing.

The search in specialized databases are the main source of this research allowing to analyze different scientific papers and recent publications, referenced throughout the study, thus allowing to understand the new technologies developed both for gas and for the analysis of operational performance of circuit breakers. Additionally, it is highlighted that all the information gathered from these papers was analyzed from a technical-research approach for achieving a deep and focused analysis on the operation and construction of these switching devices.

3. Technology monitoring

The bibliometric analysis is based on a complete review of the State of the Art in the Web of Science database in order to know the advances in a specific subject such as power switches, in terms of technological evolution, new developments, prototypes and other types of technical research. This review is done using the keywords "High-Voltage Circuit Breaker" and all the information collected for the analysis is presented below.

Figure 1 shows the record of the last ten years, from 2007 to 2017, with respect to publications, showing the highest rate of publications in 2011 and 2013, with 110 and 104 papers respectively. The year 2017 presented the lowest rates, with just two publications. However, the latest publications of research papers focus on technology trends.

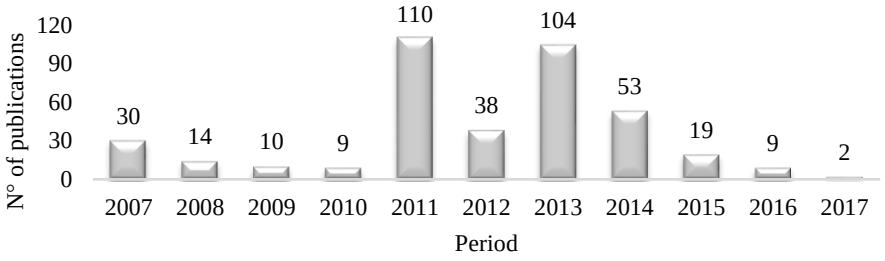

Figure 1. Publications in WoS during the years 2007 - 2017. Source: Own elaboration

It is important to note that the index of publications on issues related to circuit breakers is in English language, taking into account that they generate a higher level of impact in scientific journals or conferences where they are exposed.

Figure 2 describes the countries with the highest number of publications on issues related to power circuit breakers, technological advances or improvements in their operation, highlighting China as the country with the greatest number of publications between 2007 and 2017; 264 with respect to other countries that do not reach 80 publications, that is, the research growth in China is higher compared to other countries.

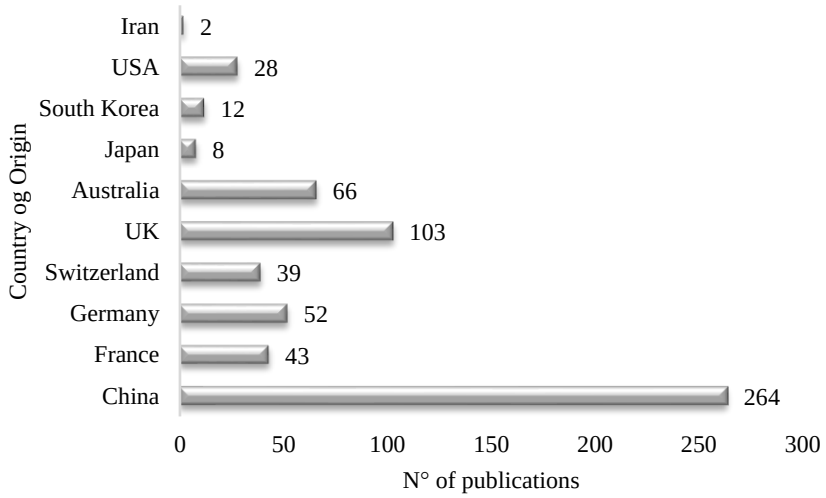

Figure 2. Publications in WoS according to the country of origin. Source: Own elaboration

Similarly, Figure 3 shows a balance of the top ten institutions with the greatest number of publications worldwide, led by Xi'an Jiaotong University with 138 publications and, in second place, is Liverpool University with 99 publications.

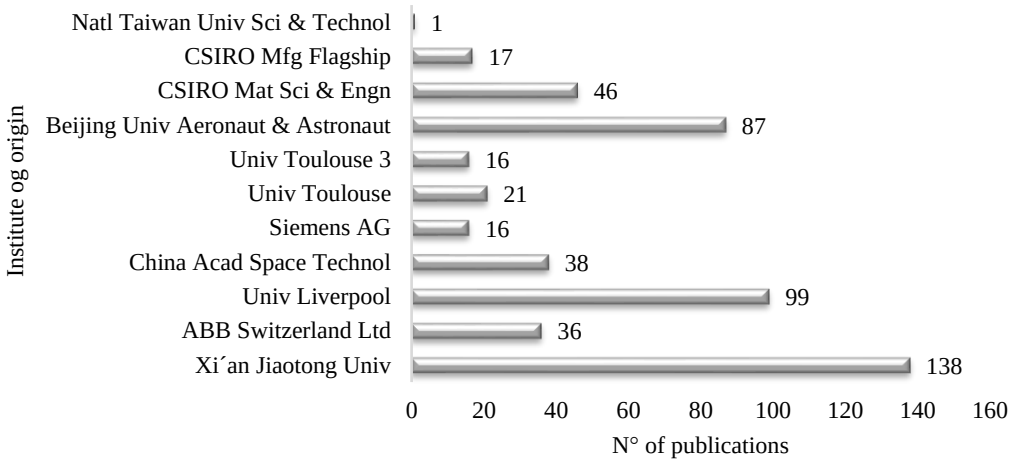

Figure 3. Publications in WoS according to the institution of origin. Source: Own elaboration

Table 1 shows the authors with the highest number of publications during the period 2009 to 2019 with the research topic on circuit breakers. The author with the largest number of articles is Mingzhe Rong from Xi'an Jiaotong University and active member of the CPC (Committee and the Standing Committee of XJTU) [11].

Table 1. Publications in WoS according to authors with high publication rates. Source: Own elaboration.

Authors	N° of publications
Rong Mingzhe	110
Wang Zhao-Wei	91
Spencer Joseph W	74
Wu Yingshuang	45
Freton Pierre	17
Gonzalez J.	17
Murphy Anthony B.	63
Yan J. D.	61
Reichert Frank	16
Seeger Michael	17

4. Selected Technologies

After a bibliometric review, and after identifying the different technologies applied in circuit breaker protection systems, such technology is recognized as the application of a multiparametric sensor system for the control of the dielectric insulation of gas mixtures [12], due to the high global warming potential of SF6 gas which has motivated the search for environmentally friendly dielectric insulation gases, allowing the conclusion that perfluorinated ketones (FK) diluted in a carrier gas have acceptable dielectric properties for application in high and medium voltage gas insulation cells (GIS).

SF6 options are based on gas mixtures, so an accurate monitoring system is required to measure FK concentration as insulation performance is a function of its composition. A robust and low-cost method was identified to derive the concentration in a mixture of binary gases using simultaneous measurements

of pressure, temperature and density, allowing two ways of performing this scheme to be tested using commercially available sensors, which achieved a relative accuracy of over 4% of the FK content. A long-term campaign was followed in which a GIS of open-air operations filled with FK based isolating gas was followed showing that the measurement is suitable for field environments. The universality of the method and its easy implementation with available equipment is important for any application requiring monitoring of the concentration of binary gas mixtures [13].

SF6 gas (Sulphur hexafluoride) offers multiple benefits as it is a closed system determined by safety and low leakage possibilities. Additionally, it is an insulating gas used in encapsulated substations because of its insulating condition and its excellent extinguishing medium for high voltage switchgear, which must be able to interrupt fault currents within the electrical power systems for which they have been sized. It has all the functions of insulator and extinguishing capacity due to its high caloric capacity and its electronegative properties.

Due to its great importance, this gas has been developed through time and, due to its impact on global warming, new technologies have been developed with reference to ecological evolution focused on the failures in these devices. The design of the insulation system of an SF6 circuit breaker can be of two types: with gas space or through the surfaces of solid dielectrics. Where the discharge conditions through the solid dielectric surfaces differ from the discharge conditions in the gas space and can be the main factor for determining the geometrical dimensions of the circuit breaker. For operation, the insulation system must withstand the standardized AC voltage and standardized surge voltages [14].

Based on the previously analyzed information in the diverse sources and databases, there is a great relationship focused on the ecological environment and the protection of these devices, allowing the analysis of the diverse options with the SF6 gas without altering its composition and adding ecological factors which, in effect, improve the performance within the device.

One of the key technologies for high voltage intelligent switchgear (SF6) to verify the self-assessment of the reliability of its operation and allow it to control reliability locally and independently is based on a methodology that evaluates the information from a single multi-parametric sensor and is completed with the evaluation of multiple sensors. The evaluation is conducted in two steps: In the first step, the trending method and the fingerprint method are implemented, and one of the methods, suitable for the information from the single sensor, is selected. In the second step, the independence between the sensor information is analyzed and three types of probable incidence relationships are proposed and applied in the calculation of synthetic evaluation results, in which the reliability corresponding to the specific sensor value is replaced by an empirical value, making the analysis method executable [15].

5. Switching mechanisms

The operating mechanism of power circuit breakers is responsible for operating the breaker in the open or closed position for the stored energy and this must be required to perform the necessary operating sequence. If the energy stored in the breaker is not met, the failure rate will increase, and this is what normally happens. There are different types of switching mechanisms such as hydraulic, pneumatic, and SF6 gas springs.

Spring switching mechanisms where energy is stored in the spring load for the open and closed position to ensure timely tripping of the breaker. The closing spring is charged by a motor or manually with a handwheel. This type of mechanism is typically used up to 245 kV and is therefore low cost and low maintenance [4].

Pneumatic-type switching mechanisms store energy with compressed air with the main purpose of dissipating the electric arc by means of pressurized air. It is used in compressed air circuit breakers but

in oil and SF6 circuit breakers. In order to keep the air pressure constant, a compressor is used which has a pressure system to alert about the voltage levels [4].

Hydraulic-type switching mechanisms store energy with oil under pressure by means of a compressor, often used when the operating time is relatively short for a faster opening or closing reaction compared to other types of switching mechanisms [4].

Sulphur hexafluoride switching mechanisms store energy with the same insulating gas SF6 under certain conditions and pressure levels to perform the switching operation in a timely and efficient way [4].

6. Technical standards

It is very important to note that circuit breakers are ruled by technical standards, approved by the IEC - International Electrotechnical Commission, the IEEE - Institute of Electrical and Electronics Engineers, and the ANSI - American National Standards Institute, regarding the following aspects [4]:

- IEC 62271-100 High-voltage alternating current circuit breakers
- IEC 60376 Specification and acceptance of new hexafluoride
- IEC 60427 Synthetic testing of high-voltage alternating current circuit breakers.
- ANSI C37.12 AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis – Specifications Guide [16]–[23].

7. Conclusions

Based on the bibliographic study analyzed above, it is highlighted that the current implementation of Sulphur hexafluoride, commonly known as SF6, is a gas used for the dielectric insulation of power circuit breakers and other equipment in the substations in order to dissipate the electric arc in the shortest time possible during the operation of the equipment [24]. SF6 circuit breakers are safe for the environment, as long as there is no leakage of the gas into the atmosphere because its influence on global warming is high and research is being carried out at international level to find alternative gases. SF6 is also recognized as a greenhouse gas since 1997 and for this reason its use and emissions into the atmosphere are regulated by international treaties (Kyoto Protocol) [25], [26].

In order to adapt SF6 to the different environmental requirements, new switch designs are implemented with construction features to limit possible unwanted gas leaks or escapes, [27]. It is important to highlight that the deterioration of the external part of the equipment would also generate an impact on global warming because it would allow the escape of gases. For this reason, it is of great importance to carry out the life cycle assessment with respect to the release of CO2 in the life time of the equipment [27], [28].

Although no other gas is suggested for the dielectric insulation of the equipment in a substation, on the basis of the results, it can be established that the significantly improved properties of SF6 with respect to typical SF6/N2 mixtures or others already used, allow SF6 to be replaced on a transient basis by evaluating the behavior of the equipment through technical tests [24]. One of the methodologies to be implemented in the future are the concentrations of SF6 and N2 that are calculated from the thermal conductivity function of the mixing gas, in a specially designed thermostatic chamber with an adaptive temperature regulator to ensure constant gas pressure inside the thermal conductivity sensor [29]–[31]. Future research works can generate a new method of dielectric insulation for the equipment in a substation without affecting its normal operation with lower pollution levels than previous technologies.

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